

[0001] RELIABILITY DETECTION OF CHANNEL QUALITY INDICATOR  
(CQI) AND APPLICATION TO OUTER LOOP POWER CONTROL

[0002] CROSS REFERENCE TO RELATED APPLICATIONS

[0003] This application claims priority from U.S. Patent Application No. 60/430,854, filed on December 4, 2002, and from U.S. Patent Application No. 60/438,560, filed on January 6, 2003, which are incorporated by reference as if fully set forth herein.

[0004] FIELD OF INVENTION

[0005] The present invention relates generally to channel quality measurements in wireless communications, and more particularly, to a method and apparatus for reliably detecting channel quality and its application to outer power loop control.

[0006] BACKGROUND

[0007] Currently, third generation (3G) mobile communication systems are being standardized to implement efficient and high throughput of downlink (DL) packet data transfer mechanisms. In the context of universal mobile telecommunications system (UMTS) wideband code-division multiple access (W-CDMA) based 3G systems, these packet transfer techniques are commonly referred to as high-speed downlink packet access (HSDPA). HSDPA is possible for both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) modes, and is implemented for chip rates of 1.28 Mcps and 3.84 Mcps.

[0008] The following characteristic features are the source of recognized efficiency and achievable data throughput of HSDPA: Adaptive Modulation and Coding (AMC) techniques; fast Hybrid Automatic Repeat Request (Hybrid ARQ); fast feedback mechanism for uplink (UL) reporting of instantaneous DL channel quality; and radio

resource efficient packet scheduling mechanism and fast, short-term DL channel assignments.

[0009] Yet another distinguishing feature of HSDPA is that the data rate and amount of DL transmission (Tx) power that an HSDPA base station allocates to a wireless transmit and receive unit (WTRU) is a function of the WTRU's instantaneous channel conditions. For example, a user close to the base station can reliably receive a high HSDPA data rate with low transmission power. A user far away from the base station, or a user confronted with unfavorable channel conditions, would only support a reduced data rate for the same or higher amount of allocated DL transmission power.

[0010] The instantaneous HSDPA data rate that a particular user can reliably support is generally dependent on: 1) path loss, which is based on the distance to the serving base station; 2) shadowing; 3) instantaneous fast fading conditions; 4) interference at the user's receiver caused by other users present in the system; and 5) the user's channel conditions, such as the speed and propagation environment. In other words, the HSDPA data rate is a function of the user's experienced DL signal-to-interference ratio (SIR) which is based upon all of these factors and is representative of the DL data rate that the user can support. The user's DL SIR will generally vary in time as a function of these factors.

[0011] Knowledge of the user's experienced DL SIR or any similar representative metric with this functionality, for example BLER, BER, or received signal power combined with received DL interference, is essential for the HSDPA base station to ensure highly efficient HSDPA operation. CDMA systems employing HSDPA have therefore adopted a fast UL Layer 1 (L1) signaling mechanism which allows a WTRU to periodically report the DL SIR to the base station with a fast, UL channel quality indicator (CQI). The current FDD specification allows configuration of the periodic CQI feedback in the UL to be sent every 0 (when CQI reporting is turned off), 2, 4, 8, 10, 20, 40, 80, or 160 ms. However, in TDD there is no periodic CQI feedback, so the CQI is instead sent with an ACK/NACK on the High-Speed Shared Control Channel (HS-

SICH) whenever a DL data block on the HSDPA Data Channel (HS-DSCH) is received by a WTRU. In W-CDMA FDD and TDD modes, this mechanism is commonly referred to as CQI reporting.

[0012] The method for measuring a CQI in a particular WTRU implementation is not standardized, but is open to vendor implementation. But the method of how to derive the reported CQI value is standardized. In the FDD standard, there is a table (as shown in 3GPP TS 25.321, Medium Access Control (MAC) Protocol Specification, 5.4.0 (2003-03)) listing some 30 CQI values roughly corresponding to increasingly higher data rates, and therefore proportional to higher and higher DL SIRs. The reported CQI in FDD is derived as follows (per 3GPP TS 25.214, Physical layer procedures (FDD), v5.4.0 (2003-03), section 6A.2): “the UE shall report the highest tabulated CQI value for which a single HS-DSCH sub-frame formatted with the transport block size, number of HS-PDSCH codes and modulation corresponding to the reported or lower CQI value could be received in a 3-slot reference period ending 1 slot before the start of the first slot in which the reported CQI value is transmitted and for which the transport block error probability would not exceed 0.1.” In TDD, the reporting is different; the transport block size is reported if it was transmitted during the last received transmission interval (the number of timeslots where the last HS-DSCH was received) and that transmission would have yielded a block error rate of 0.1.

[0013] As an example, in the current W-CDMA FDD release 5, the CQI is an information bit sequence five bits long which is encoded by means of a (20, 5) Reed-Muller code. The resulting 20 bit long coded sequence is sent in the UL on a High-Speed Dedicated Physical Control Channel (HS-DPCCH). Every user has a separate HS-DPCCH with an adjustable CQI reporting cycle (feedback rate). A user can report the CQI on the HS-DPCCH even if the user does not receive data on the HS-DSCH.

[0014] As another example, in the current W-CDMA TDD release (3.84 Mcps or high chip rate (HCR) TDD), the CQI is an information bit sequence ten bits long which

is encoded by means of a (32, 10) Reed-Muller code. The resulting 32 bit long coded sequence is sent in the UL as part of the HS-SICH. With current TDD, a CQI transmission can only take place if the user has previously received data on the HS-DSCH in the frame.

[0015] Because the reliability of a WTRU's CQI report has an impact on HSDPA operation, it is important that an HSDPA base station has a means of determining whether a CQI was received in error. By discarding any erroneously received CQI, the HSDPA base station can avoid the situation in which it would choose a DL data rate and corresponding transmission power for a user that is not adapted to the user's experienced DL channel conditions. Erroneous CQIs reduce the HSDPA data throughput to the user and create a high level of interference to the other users in the system, which reduces the efficiency of HSDPA service in the W-CDMA system.

[0016] Furthermore, too many CQIs received in error from a particular user are an indication that the user's UL transmission power settings are not accurate and the base station or another access network node, such as the Radio Network Controller (RNC), will take appropriate actions. As an example, the RNC can signal a higher target UL SIR to the user in order to increase its UL transmission power and to lower the error rate on HS-DPCCH (in FDD) or HS-SICH (in TDD). This type of RNC functionality is commonly referred to as outer loop power control.

[0017] Error detection of received UL transmissions in W-CDMA FDD and TDD modes is typically accomplished by employing a Cyclic Redundancy Check (CRC), i.e., a bit sequence computed from and accompanying the data which, when decoded in error in the base station, is a reliable indicator of decoding errors. For a CRC to be effective in error detection, the length of the CRC must be sufficiently large. However, in order to avoid having an inefficient process, the ratio of the CRC length to the actual data length must be small. In a typical application, the data may be on the order of hundreds of bits while the CRC field may be on the order of 8-24 bits.

[0018] Unfortunately, the HS-DPCCH (FDD) and the HS-SICH (TDD) are fast L1 UL signaling channels which do not include any UL data or a sufficient number of L1 signaling bits to make efficient use of a CRC. To provide sufficient error detection capabilities, the CRC would have to be nominally at least the same size as the data field that it is verifying. With these considerations, current HSDPA standards do not use a CRC on the HS-DPCCH (FDD) and the HS-SICH (TDD).

[0019] Therefore, based on existing techniques the network (base station or RNC) has no means of reliably determining whether or not a CQI was received in error or not. The network can only configure the WTRU to use a high enough UL transmission power by means of an UL target SIR and by “experience” from simulations, such that the event of errors is sufficiently unlikely and not detrimental to HSDPA system operation. It is therefore advantageous to provide a method for reliably detecting and reporting the correctness of received CQI values.

[0020] SUMMARY

[0021] The method of the present invention enables the base station to determine the degree of reliability of the CQI. The present invention provides a useful reliability detection mechanism for a CQI report received by the HSDPA base station from a WTRU and provides a received CQI quality reporting mechanism from the HSDPA base station to the RNC in order to track and adjust a WTRU's UL transmitting power setting.

[0022] A method for improving the reliability of a channel quality indicator (CQI) message in a wireless communications network begins with receiving and decoding the CQI message. A decision metric value for each symbol in the CQI message is computed. A largest decision metric value and a second largest decision metric value are determined. The reliability of the CQI message is determined by comparing the largest decision metric value and the second largest decision metric value.

[0023] A method for improving the reliability of a received message representing quality of a transmission channel in a wireless communication system begins by receiving a channel quality indicator (CQI) message from a wireless transmit and receive unit. The CQI message is then decoded, and at least two different values representative of the decoded CQI message are obtained. The reliability of the CQI message is determined by comparing the at least two values.

[0024] A system for determining the quality of a transmission channel in a wireless communication system includes at least one wireless transmit and receive unit (WTRU) and a base station. The WTRU includes generating means for generating a channel quality indicator (CQI). The base station includes receiving means for receiving the CQI, decoding means for decoding the CQI, computing means for computing a first decision metric and a second decision metric of the decoded CQI, and comparing means for comparing the first and second decision metrics to determine if the CQI contains an error.

[0025] An integrated circuit constructed in accordance with the present invention includes an input configured to receive a channel quality indicator (CQI) message, decoding means for decoding the CQI message, computing means for computing a first decision metric and a second decision metric of the decoded CQI message, and comparing means for comparing the first and second decision metrics to determine if the CQI message contains an error.

[0026] BRIEF DESCRIPTION OF THE DRAWINGS

[0027] A more detailed understanding of the invention may be had from the following description of preferred embodiments, given by way of example and to be understood with reference to the accompanying drawings, in which:

[0028] Figure 1 is a flowchart of a method in accordance with the present invention, applicable to both FDD and TDD;

[0029] Figure 2 is a flowchart of an alternate embodiment of a method in accordance with the present invention, applicable to both FDD and TDD;

[0030] Figure 3 shows an example of CQI reliability detection, applicable to both FDD and TDD;

[0031] Figure 4 is a graph of the additive white Gaussian noise (AWGN) channel HS-SICH performance, from TDD simulations; and

[0032] Figure 5 is a graph of the WG4 test case 2 channel HS-SICH performance, from TDD simulations.

[0033] DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

[0034] As used and described hereafter, a WTRU includes, but is not limited to, a user equipment, a mobile station, a fixed or mobile subscriber unit, a pager, or any other type of device capable of operating in a wireless environment. When referred to hereafter, a base station includes, but is not limited to, a Node-B, a site controller, an access point, or other type of interfacing device in a wireless environment.

[0035] Figure 1 illustrates a method 100 for determining the reliability of a CQI and its application to outer loop power control in accordance with the present invention. The method 100 begins by initializing a time interval clock and several counters, such as total HS-SICHs received, number of false HS-SICHs received, and number of HS-SICHs that have been missed (step 102). The CQI is received (step 104) and decoded (step 106). For each symbol in the CQI, a decision metric value is computed (step 108). The two largest decision metric values are selected (step 110) and the difference between the two largest values is determined (step 112). The difference between the two largest decision metrics is evaluated to determine if it is below a threshold (step 114). If the difference is below the threshold, then the CQI is likely to be in error, so it is discarded (step 116).

[0036] If the difference meets or exceeds the threshold, then the CQI is presumed to be valid (step 118). Next, the counters are incremented (step 120) and a

determination is made whether the end of the time interval has been reached (step 122). Also, flow passes back to step 104; the loop of steps 104-120 repeats continuously, regardless of the value of the counters or whether the time interval has expired.

[0037] If the time interval has expired (step 122), then a determination is made whether the counters meet or exceed a threshold value (step 124). If the counters are equal to or greater than the threshold, the RNC is signaled (step 126), the RNC then signals the WTRU to adjust the UL transmission power (step 128), and the method ends (step 130). If the end of the time interval has not been reached (step 122) or if the counters are below the threshold (step 124), then the method ends (step 130).

[0038] It is noted that the difference determined in step 112 is applicable when the metric are logarithmic, i.e., in dB. If the metrics are in pure numbers, then steps 112 and 114 can be modified as follows. The ratio of the largest decision metric to the second largest decision metric is calculated (step 112) and the ratio is compared to the threshold (step 114).

[0039] A similar alternate method involving additional Iub signaling entails simple periodic reporting of the total number of HS-SICHs received, the number of false HS-SICHs received, and the number of HS-SICHs that have been missed over a fixed time period and reporting these numbers without regard to error thresholds. This type of periodic reporting would add more Iub signaling, but would be less complex to implement in the Node B.

[0040] Figure 2 shows an alternate method 200 for determining the reliability of a CQI and its application to outer loop power control in accordance with the present invention. The method 200 begins by initializing several counters, such as total HS-SICHs received, number of false HS-SICHs received, and number of HS-SICHs that have been missed (step 202). The CQI is received (step 204) and decoded (step 206). For each symbol in the CQI, a decision metric value is computed (step 208). The two largest decision metric values are selected (step 210) and the difference between the two largest values is determined (step 212). The difference between the two largest decision

metrics is evaluated to determine if it is below a threshold (step 214). If the difference is below the threshold, then the CQI is likely to be in error, so it is discarded (step 216).

[0041] If the difference is above the threshold, then the CQI is presumed to be valid (step 218). Next, the counters are incremented (step 220) and a determination is made whether the counters meet or exceed a threshold value (step 222). Also, flow passes back to step 204; the loop of steps 204-220 repeats continuously, regardless of the value of the counters.

[0042] If the counters are equal to or greater than the threshold, the RNC is signaled (step 224), the RNC then signals the WTRU to adjust the UL transmission power (step 226), and the method ends (step 228). If the counters are below the threshold (step 222), then the method ends (step 228).

[0043] When the base station decodes the received 32 bit code word (steps 106, 206), the output of the decoding process can be viewed as one of  $N$  distinct hypotheses, where the number of information bits  $n$  is related to  $M$  by  $M=2^n$  (in TDD,  $n=10$ ). In other words, one out of  $M$  symbols is sent from the WTRU to base station. The hypothesis test at the base station selects the most likely member of the  $M$  symbol alphabet, and then converts it back into the  $n$  information bits that the symbol, i.e., the encoded code word, represents.

[0044] Different decision algorithms exist to determine what represents the most likely received symbol, often varying on what is known about the symbols. For example, if it is more likely that a particular symbol is sent, then incorporating this knowledge into the decision algorithm provides an advantage over an algorithm which supposes that all symbols are sent equally often. To further illustrate, in the FDD context, the decoder can operate like 32 matched filters, with one filter for each symbol, wherein each symbol has a particular waveform (chip/bit sequence). Each matched filter correlates the received waveform with the waveform corresponding to a particular symbol. The correlation outputs from each of the 32 matched filters is basically a peak corresponding to energy. A large peak means that “very likely this was the symbol

sent” (wherein a code word is equivalent to a chip sequence), and a small correlation peak means that “unlikely this was the right symbol.” Then, the largest peak out of the 32 obtained peaks is selected and is determined to be the symbol that was sent. Because this is a statistical hypothesis test, on average the determined symbol is the best decision that can be made. An example of this process is shown in Figure 3. The decoding process in the base station converts a sequence of received channel bits into soft decision metrics for every possible one out of M CQI symbols. The CQI quality detector can be implemented in a single integrated circuit or as discrete components.

[0045] In general, the information bit sequence (the CQI word) is  $n$  bits long. The CQI word is encoded to a  $(N,n)$  Reed-Muller code, which consists of  $M (= 2^n)$   $N$ -bit long encoded bit sequences. For example, in TDD, there are  $n=10$  information bits, which results in 1024 ( $M=2^{10}$ ) possible encoded words of length  $N=32$  bits each. The process of encoding the CQI on the HS- SICH provides some repetition, which maps each of the  $N$  coded bits into  $N*4=L$  channel bits. Every channel bit is spread by a spreading factor of 16 (i.e., a 16 chip long spreading sequence), resulting in  $L*16 = C$  chips. In TDD, the CQI word is generally encoded using a  $(32,10)$  Reed-Muller encoding and  $n = 10$ ,  $N = 32$ ,  $L=128$ ,  $C = 2048$ . Without loss of generality, the same principle of the method is also valid for FDD with a  $(16,5)$  encoding.

[0046] As those of skill in the art would realize, any other type of encoding scheme may be used, and the present invention is not limited to the schemes set forth herein. An arbitrary  $(N,n)$  encoding scheme as known by channel coding theory and existing for the choice of parameters  $n$  and  $N$ , determining its ratio of information bits to coded channel bits would operate with the present invention. For example, a Reed-Muller first or second order code or a Reed-Solomon code could be used. The particular coding scheme on the  $(N,n)$  bits is not significant, as long as the decoder can compute discrete decision metrics for each and every symbol that can be sent over the channel.

[0047] Steps 110 and 112 of Figure 1 and steps 210 and 212 of Figure 2 represent one possible method to determine CQI reliability. Numerous other methods for

determining CQI reliability are possible. For example, the ratio of the greatest or largest decision-metric to the second greatest, or the difference between these two metrics in dB ( $10 \log(\text{ratio})$ ) may be used. To illustrate by way of some simple equations, if  $P_{\max}$  denotes the value of the largest observed peak and  $P_{\text{second}}$  denotes the second-largest observed peak, the ratio (R) could be expressed as  $R = P_{\max}/P_{\text{second}}$  or  $\log(P_{\max})/\log(P_{\text{second}})$  or more generally as  $f(P_{\max}/P_{\text{second}})$ . Another proposed method of determining CQI reliability is the ratio of the energy of the greatest decision metric to the sum or a weighted sum of the energy of the set of M-1 other decision metrics. For example,  $P_i$  ( $i=1\dots32$ ) are values of the observed peaks at the output of the Reed-Muller decoder.  $P_{\max}$  is the maximum  $P_i$  value. The measure R is expressed as  $R = P_{\max} / (\sum P_i - P_{\max})$ .

[0048] By comparing the soft decision metrics of the decoded CQI symbols, the base station can employ a simple threshold-based decision mechanism in order to decide whether the received CQI symbol is likely to be or not to be in error (steps 114, 214). As an example, if the difference between greatest and second greatest metric is less than 1 dB, there is a very high probability (typically, greater than 95%) that the CQI is in error and the CQI should be discarded. Other difference values may be used, with a corresponding reduced probability of the CQI being in error. A preferred range for the difference is between 0-2 dB, so that the probability of the CQI being in error is sufficiently high.

[0049] An example of the CQI reliability detection method performance in terms of the ability to detect CQI errors for the TDD case is shown in Figures 4 and 5. Figures 4 and 5 include graphs for BER after MUD, ACK->NACK BER, NACK->ACK BER, rejected CQIs, rejected CQIs which were good, and not rejected CQIs which were false. The graphs also include RMF BER, which is the first bit of the ten bit long CQI word and indicates the Recommended Modulation Format (either QPSK or QAM). The graphs show the BER for this single bit. The RTBS includes the other nine information bits in the CQI word and they denote the Recommended Transport Block Set, which is

the number of information bits in the HS-DSCH transport block that the WTRU recommends should be sent. The graphs show the word error rate (WER) of these nine bits, which indicates the probability that at least one of the nine RTBS bits is in error.

[0050] The following observations may be made from Figures 4 and 5: 1) the ACK/NACK soft decision threshold is at  $0.1 \times \text{signal amplitude}$ ; 2) the criteria to reject a CQI includes the highest/second highest correlation peaks less than 1 dB away in amplitude; 3) erroneous CQIs can be readily detected; and 4) the ratio of “correct CQIs falsely rejected” to “wrong CQIs not rejected” can be easily scaled to meet target errors.

[0051] Thus, an improved CQI field coding is made possible by the use of the present invention. Under previous methods, when the HS-SICH carrying the ACK/NACK and the CQI was received, there was no means of knowing if the received HS-SICH fields (either the ACK/NACK or the CQI) were received in error, because there was no CRC. If the ACK/NACK is received in error and the Node B does not realize this, the Node B could, for example, retransmit a packet that was already received successfully in the WTRU or discard (not retransmit) a packet which it should have retransmitted and WTRU waits for an extended period of time for a packet that will never arrive and memory stalls. The CQI reliability detection according to the present invention allows the Node B to indicate which received HS-SICHs are reliable and can take appropriate actions, like retransmission. Also, in order to ensure reasonably often ( $<1\%$  of the cases when received) that the HS-SICH is reliable, the HS-SICH needs to be received at a high SNR. This means that the WTRU must transmit at a higher power. Because the WTRU does not have much power and to be able to maximize coverage, the WTRU's transmission power must be sufficient to meet the average HS-SICH BER of 0.1. The proposed CQI reliability detection methods provide the Node B, via reporting the CQI, the means of tracking the current transmission power settings in the WTRU and the means to adjust the power settings.

[0052] Furthermore, the reliability detection method can also be used to provide indicators to the HSDPA base station and the RNC on HS-SICH / HS-DPCCH

performance and CQI reporting, to alert the HSDPA base station that the CQI value may be in error. It is also possible to alert, through a message from the HSDPA base station to the RNC via the Iub/Iur network interfaces, that the delivered SIR may be inadequate. Simple statistics are provided, such as how many received HS-SICHs received from a particular WTRU were declared in error based on CQI metrics, how many total HS-SICHs were received over the same time period, and how many HS-SICHs were declared not to have been sent at all. These are functions that would normally be provided by a CRC and which now are possible due to the CQI reliability test based on soft decision metrics.

[0053] According to a particular aspect of the invention, new messages are added to the Iub/Iur network interface to define occurrences of the number of failures of a transmission and the number or occurrences of symptom-free receptions, i.e., to report that a given WTRU has sent X successive UL HS-SICH messages without a failure being reported.

[0054] Upon reception of a predetermined number of CQI failure indicators related to a particular WTRU or HS-SICH channel, either the HSDPA base station or the RNC can take appropriate actions, such as changing the power control parameters for the WTRU or the HS-SICH channel, or discarding CQIs and using previous CQI reports for DL HSDPA transmissions. In one embodiment of the present invention (shown in Figure 1), counts are taken over 200 ms time intervals. In each frame (which is 10ms long), there can be at most one HS-SICH received from a WTRU, so therefore there are at most 20 HS-SICHs in 200ms. All counters are defined from 0...20 (total received HS-SICHs, false HS-SICHs, and missed HS-SICHs).

[0055] Even though the examples given above are directed to HSDPA TDD, the invention is equally applicable to HSDPA FDD and other modes of transmission, for obtaining improved CQI reliability detection and improved outer loop power control. While specific embodiments of the present invention have been shown and described, many modifications and variations could be made by one skilled in the art without

departing from the scope of the invention. The above description serves to illustrate and not limit the particular invention in any way.

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